SEALING CRACKS IN FLEXIBLE PAVEMENTS

INTERIM REPORT I

FLEXIBLE PAVEMENT CRACK SEALING PRACTICES
AND RESEARCH APPROACH

by

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CHAPTER I

INTRODUCTION

In response to a request from the Research Division, a research proposal entitled "Sealing Cracks in Flexible Pavements" was presented to the Oklahoma Department of Transportation in February, 1976. This proposal was for a three year study to begin July 1, 1976. The proposed study was primarily devoted to evaluating the effectiveness of various materials and methods of application for sealing flexible pavement cracks. Secondary objectives of the proposed research included developing crack survey and monitoring techniques, measuring pavement movements at crack interfaces and establishing criteria for crack sealing operations and the selection of sealants.

This proposal was examined and accepted by the Research Division for inclusion in their contract research program. However, certain recommendations were made for revising the proposed research relative to the investigative approach and the timing of the activities. These revisions in the basic proposal were needed to make the project work conform more closely to the needs of the ODOT and to avoid overlap with an in-house research investigation.

Another aspect of the recommendation received from the ODOT was that the project be funded initially for only a six-month period. During this time, an extensive examination of the pertinent literature was to be made and a more detailed work plan for 1) a laboratory investigation and evaluation of crack sealing materials and 2) a field study of crack dynamics, i.e., the horizontal and vertical movements of the pavement at crack locations, was to be submitted. These requirements were to be carried out before extending the project and providing additional funding.

It is believed that this interim report fulfills both of the stated requirements. Chapters II and III outline the results of the review of literature and the questionnaire survey of in-state and out-of-state maintenance personnel. Chapter IV presents a suggested research approach for the laboratory work on sealants and the field study of crack movements. In the interest of brevity, detailed test procedures have been omitted since most of the proposed laboratory tests are ASTM tentative standards.

The estimated time required to carry out the initial phases of the investigation outlined in Chapter IV is from one and a half to two years. The final phase of the research, conduct of a field test program of sealants and application procedures and development of equipment and techniques for rapid crack surveys, will require approximately the same amount of time. Detailed work plans for this last phase, based on further study of the literature and results of the initial phases of the study, will be submitted at a later date for ODOT consideration.

CHAPTER II

LITERATURE SURVEY

Sealants

The problem of sealing cracks in flexible pavements is, perhaps, more formidable than that of sealing joints in rigid pavements. Flexible pavement cracks have no regular or uniform interfacial space in which preformed gasket material can be placed, the irregular and often times contaminated (dust and moisture) interfacial surfaces prevent good adherence of cold-poured elastomeric type sealants, and there is the possibility of lack of compatibility between the sealant material and the asphalt binder in the pavement.

The materials currently being used for sealing cracks in flexible pavements can be separated into two broad catagories, hot-poured sealants and cold-poured materials. An investigation conducted by Cook (1) showed that the hot-poured materials were used for this purpose more frequently.

Hot-Poured Materials

Hot-poured sealants are either straight-run asphalt cements or asphalt cements that have been modified by the addition of mineral fillers and/or rubber (1, 2, 3, 4, 5). The use of paving-grade asphalt cements seems to be limited to certain types and widths of cracks (4), e.g., in the case of very narrow crack openings, these asphalts tend to bridge over the crack and do not penetrate deep enough to provide an effective seal.

It has been reported that the addition of rubber improves the flexibility, ductility, adhesion and cohesion properties of asphalt cement (6, 7). The beneficial aspects of using rubberized-asphalt, containing 20 to 35% rubber by weight, as a crack sealing material have been demonstrated by many investigators (1, 3, 5, 8, 9, 10). In some reports, the rubber additive used was ground recycled tire rubber and this material may also have both economical and ecological advantages in view of the rising cost of asphalt cement.

Sulphur has also been used as an additive to improve the resilience of asphalt cement used as a joint filler. Also, many kinds of pulverized mineral fillers, e.g., talc, limestone and silica, have been used to harden or inverse the viscosity of asphalt cements (5).

Cold-Poured Materials

Cold-poured sealants include liquid asphalt materials such as cutbacks, standard emulsions, and rubber-asphalt emulsions (1, 2, 4, 6). Apparently, little or no use of cold-poured elastomeric materials for sealing flexible pavement cracks has been reported (1). Most of the liquid asphalt products that have been used for sealing cracks are included in the following list recommended by the Asphalt Institute (4):

Cutbacks........................		RC-70
Emulsions...........	(Anionic)..	RS- 1
	(Anionic)..	SS-1, in slurry mix
	(Anionic)..	SS-1h, in slurry mix

Emulsions...........(Cationic).. CRS-2
(Cationic).. CSS-1, in slurry mix
(Cationic).. CSS-ih, in slurry mix

Laboratory Investigations of Sealants

Tons (11) summarized the major factors influencing the performance of a sealant as 1) the characteristics of the crack to be sealed, 2) properties of the sealant to be used, 3) properties and conditions of the sealant-crack interface, 4) quality of workmanship (related to application of the sealant), and 5) types of service to which the sealed crack is subjected. Under various field conditions the sealants may fail in adhesion, cohesion, extrusion, or a combination of these three types of failures (see Fig. 1).

Adhesion failure is simply a loss of bond between the sealant and the crack wall under a tensile load. This happens during contraction of the pavement when the sealant builds up tensile stresses at the bond interfaces and it has no inherent ability for stress relaxation (11). Such sealants may also cause tensile failure (parallel cracking) of the surfacing if the bond strength exceeds the tensile strength of the bituminous concrete adjacent to the sealed crack. Adhesion failure was reported as the type most frequently observed under field conditions despite the fact that the sealants showed no signs of adhesion weakness in laboratory tests (2, 11).

Cohensive failure is a tearing or pulling apart of the sealant material and is a manifestation of a weakness of the forces binding together the molecules of the material. This failure also occurs

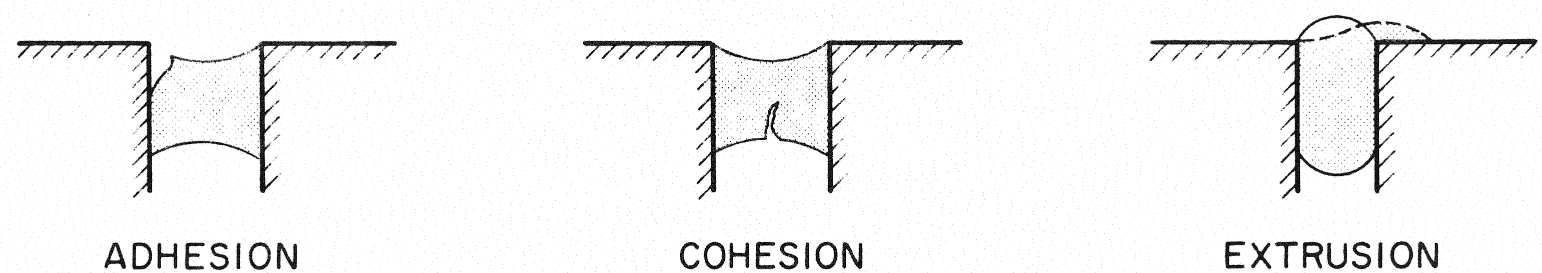


Figure 1. Types of Crack Failure (1)

during contraction of the pavement and is caused by stresses that exceed the inherent tensile strength of the sealant. Observation of sealed crack test sections indicated that most materials that successfully passed laboratory tests designed to check this characteristic showed little or no cohesion type failure in the field (2).

Extrusion failure occurs during hot weather as the pavement expands and the sealant is compressed. A portion of the sealant material is extruded above the pavement surface and, under the action of vehicle wheels, is flooded or flattened onto the adjacent pavement surface. The flattened portion of the material cannot recover and no longer serves its intended function.

Based on the aforementioned factors affecting sealant performance and the respective types of sealant failure, some idea as to the properties and characteristics of a good sealant can be obtained. Tons (12) outlined what he called "the established criteria for a satisfactory crack sealer" as follows:

1. The sealer should possess a good adhesion property that will enable it to adhere firmly to the cracked surfaces to seal it effectively under any conditions.

2. The sealer should withstand repeated stretching and compression over long periods, i.e., it should have good cohesion characteristics.

3. The sealer should neither flow out of the crack nor change its properties when exposed to hot weather.

4. The sealer should not shrink excessively due to cooling or evaporation of solvents so as to eliminate the need for repeated pouring.

5. The sealer should not extrude or become tacky on its exposed surface during high summer temperatures.

6. The sealant should not react with asphalt, salt, oil, etc.

7. The sealant material should be durable and should neither harden nor soften with age.

The ASTM tentative specification, D 3405-75T (13), for hot-poured crack sealant materials stipulates almost the same requirements and lists an additional one pertaining to compatibility of the sealant with the asphalt binder in the pavement. That is, there should be no formation of an oily exudate at the interface between the sealant and the asphalt concrete nor any softening or other deleterious effects from the sealant.

Selected Laboratory Tests

Bond-Ductility Test

This appears to be a basic test used by many investigators (1, 12, 13, 14, 15, 16) to evaluate a sealant material as to its bond or adherence to the cracked surfaces and to its stretchability or ductility at low temperatures. Essentially, the test consists of pouring sealants between spaced specimen blocks and then pulling the blocks apart at a specified rate on an extension machine. The temperature and amount of extension of the sealant are controlled. After a certain amount of extension is reached, the test samples are recompressed to their initial width at lab temperature and this constitutes a cycle. Table I lists the major features of bond-ductility tests used by several investigators and the ASTM tentative test procedure. Cook (1) has described a number of extension machines developed for this type of test by various agencies.

In this type of test, the sealing material, because of its limited

TABLE I

MAJOR FEATURES OF BOND-DUCTILITY TESTS
USED BY INVESTIGATORS AND ASTM

Test Features	Agency or Investigators		
	ASTM. D3407-75. (13)	Egon Tons. (12)	William Kuenning. (16)
Block Material Used	Mortar Blocks	Bituminous concrete cut from an old resurfacing	Concrete Blocks
Block Dimensions (in.)	1 x 2 x 3	2½ x 2½ x 2½	2½ x 4 x 8
Initial Block Spacing (in.)	1/2	1/8 and 1/2	1/8, 1/4, 3/8 and 1/2
Final Block Spacing (in.)	a. 3/4 b. 1	3/8	--
Rate of Extension (in./hr.)	1/8	1/8	1/32
Extension Percentage (%)	a. 50 b. 100	300	Vary from 60 to 160
Extension Temperature (°F)	a. -20 b. 0	5	Vary from 0 to 73
Recompression	Specimens warmed to room temperature & compressed to initial width by placing one block over the other.	Specimens warmed to 80°F for two hours & compressed to initial width by hand at rate of 0.1 in./minute.	--
Number of Cycles	3	5	Until failure
Failure Criteria	Development of crack, separation, or other opening in the sealer or between the sealer and the block during the test.	1. Separation at any place of more than 1/4 in. deep. 2. Opening of more than 1/2 in. at any direction in the sealing material. 3. Opening of more than 1/8 in. in the exposed surface connected with voids inside specimen.	Cohesion or adhesion failure.
General Description of Extension Machine	An extension machine that can expand 1/2 in., at a uniform rate of 1/8 in./hr., suitable for testing three specimens simultaneously. Requires environmental chamber	Consisted essentially of two screws, rotated by an electric motor. Uniform stretching rate of 1/8 in./hr. Capable of testing two specimens at the same time. Requires environmental chamber.	Built in PCA laboratories, Rate of stretching = 1/32 in./hr. Mounted on casters for ease of transfer. Requires environmental chamber.

dimensions, accommodates to the stretching action by becoming concave on all four of its exposed surfaces (14). In an actual crack, the sealer becomes concave only on its top and bottom surfaces due to its greater length. Thus, any given amount of crack opening will impose a greater strain on the sealing material than the same amount of extension of a laboratory specimen. This problem was realized by a number of investigators (1, 12, 14, 16, 17) and they recommended the use of fairly long test specimens. Cook (17) determined that a six inch specimen length was probably the optimum based on reducing the amount of error between field and laboratory results and the practicality of the test specimen dimensions.

Penetration Test

This test is performed on hot-poured materials to obtain a measure of the consistency of the sealant. The test procedure is outlined in ASTM D 3407-75T (13) and employs a penetration cone instead of the standard needle. Tons (12) tested the penetration of the sealers that he employed according to the procedure of Federal Specification 55-5-164 (18).

Flow Test

The flow test is designed to show the mobility or amount of flow exhibited by the sealant (hot and cold-poured mastic type materials) at elevated temperatures. A specified size of sample is poured onto a tin panel, allowed to cool, and the placed at a 75 degree angle of inclination in a 140°F oven for five hours. The change in length of the sample in millimeters is reported as the flow. The test procedure is outlined in

ASTM D 3407-75T (13) and in the Federal Specification 55-5-164 (18).

Resilience Test

This test procedure is detailed in ASTM D 3407-75T (13) and measures the capability of a sealant specimen to recover its size and shape after being deformed. A minimum recovery of 60% for a sealant is specified in ASTM D 3405-75T (13).

Compatibility Test

The compatibility test is used to determine if a sealant is compatible with the asphalt in the pavement, i.e. does the sealant have any kind of deleterious effects on the asphalt concrete. The test method and failure criteria are outlined in ASTM D 3407-75T (13).

Pour-Point and Safe Heating Temperature Tests

These tests apply primarily to hot-poured type sealants. The pour-point test determines the range of temperatures in which the sealers can be poured in both narrow and wide cracks. The safe heating temperature is the highest temperature to which the sealant can be heated without the danger of catching fire or damage to the sealant. These tests are outlined in Federal Specification 55-5-164 (18).

Other Tests

Some additional tests on sealants have been devised and reported by Tons and Roggeveen (12). The "volume change test" was used to check the shrinkage of the sealants (primarily cold-poured materials) during a specified curing time after pouring in order to determine whether repouring would be necessary in the field. The "tackiness test" was used as an indication of the amount of adhesion or pick-up of the sealant on rubber tires that could be expected. The "age hardening test" provided a relative measure of the hardening and skin forming tendencies of a sealant after a 28 day exposure to the elements.

Field Application Experience

Many different crack sealing procedures have been reported in the literature. The essential repair techniques for sealing and/or correction of various forms of cracking are discussed in the Asphalt Institute's Manual Series No. 16 (4). According to the Asphalt Institute, these sealing procedures have proven to yield neat long-lasting results.

Field studies by many agencies have been conducted to evaluate various crack sealing techniques. The investigators concluded that the amount of failure noticed depended largely on the crack preparation procedures that were used, and that the extra care exercised in cleaning and preparing the cracks prior to sealing was justified by the results obtained (2, 8, 19).

Adhesion failure was reported to be the major and most frequently observed type of failure that occurred in the sealed cracks (2, 8, 11, 19). Several approaches were tried to improve the bond between the sealer and the pavement. Cleaning the crack by some mechanical means, i.e., brooming or brushing, removed dust from the crack walls and loose paving materials. This provided cleaner and more stable crack surfaces and promoted better adhesion of the sealant. Excellent results were reported in a Minnesota field study (8) where a wire twist brush was used for this purpose.

Air-blowing and priming of the crack surfaces have also been used with conflicting results reported by various investigators. Apparently, air-blowing of the crack alone did not noticeably improve adhesion but it did allow the sealer to penetrate deeper into the crack. The reported results vary as to the effectiveness of priming cracks with a thin cutback or emulsion prior to sealing. Tons (2) believed that the prime penetrated and coated the dust on the crack walls, softened the pavement binder, and promoted better adhesion of the sealer. However, Wolter's (8) field tests of three different prime materials indicated that they should not be used. Also, slight overfilling of the sealed cracks, i.e., an overlap of sealant along the crack edges, seemed to prevent adhesion failures and provide longer service life.

Routing of cracks to relatively uniform grooves (approximately 0.5 in. wide by 1.0 in. deep) that hold more sealer than do narrow, ragged edged cracks was recommended to enhance the service life of the sealed crack (2, 8). Also, sealers in 0.25 in. or wider cracks showed considerably less failure than sealers in cracks under 0.25 in. in width. Apparently, the larger the volume of sealer in the crack, the smaller the stresses in the sealer as the adjacent pavement sections move horizontally and vertically. This conclusion corresponds with theoretical calculations (14) concerning the effect of width to depth ratio on the amount of strain in the sealer.

The sealant in a crack is similar to a short single-span bridge fixed to two abutments that move back and forth in opposite directions with temperature changes. The advantages of having the sealer become concave or "curve-in" on the top and bottom surfaces during extension was discussed by Tons (14). He indicated that, contrary to common assumptions, a relatively shallow sealed crack is better than a deeply sealed one. The shallow seal permits concavity to occur in both top and bottom surfaces and this reduces the total strain. In deeply sealed cracks, the sealant bond at the bottom of the crack prevents this. Consequently, a paper rope "bond breaker" was used to limit the penetration of the sealant in deep cracks in a field test program (8). The results of these tests were very poor, however. Nothing was found in the literature concerning the use of sand or crusher screenings for this purpose.

Crack Dynamics

Pavements are subjected to various environmental and service effects which can cause horizontal and vertical movements of adjacent sections at cracks or joints. Many studies have been made of gross pavement movements (1, 11, 20, 32) but most of these have been concerned with localized conditions and the results may not be applicable over a wider range of climatic conditions, subbase types, load-transfer systems and crack spacings. Determination of the magnitude of the relative horizontal and vertical movements at cracks that occur seasonally and under traffic loads in a particular geographic locality would be extremely beneficial to a crack sealing study.

Vertical Movement

Little data on vertical movements at both cracks and joints was found. An approach to determine the average vertical shear strain in joint sealants has been used in Massachusetts (11). In this study of rigid pavement joint movements, vertical displacements at 1.0 in. wide non-doweled joints under a 20,000 lb axle load were measured. The average shear strain of 0.01 in. was about five percent of the tensile strain experienced by the sealant and it was concluded that the effect of vertical movements on joint sealers was negligible. They did, however, indicate that further study was needed.

A method of measuring vertical movements at cracks in flexible pavements has been reported in a Virginia study (22), which was concerned with reducing reflective cracking of overlays on rigid pavements. A Benkelman beam was placed on the shoulder of the road with its point near the edge of a crack. A dump truck with an 18,000 lb rear axle load was positioned on the opposite side of the crack as shown in Fig. 2. With the loaded rear axle at point 1, an initial beam reading was taken. The truck was then driven slowly across the joint and beam readings taken as points 2 and 3 were traversed. The beam reading with the axle at point 2 indicated the deflection caused by the load on that side of the crack and comparision of the readings made with the axle at points 1 and 2 indicated the differential deflection or load transfer capability of the crack. The reading made with the axle at point 3 was used to ensure that the beam was no longer within the area of influence of the axle load.

Horizontal Movement

The horizontal displacements of roadway sections adjacent to cracks or joints in flexible pavements is much more complex, i.e., is more variable and depends on more factors, than in rigid pavements. This probably accounts for the scarcity of information on this phenomenon relative to bituminous surfaced roads. Many references were found

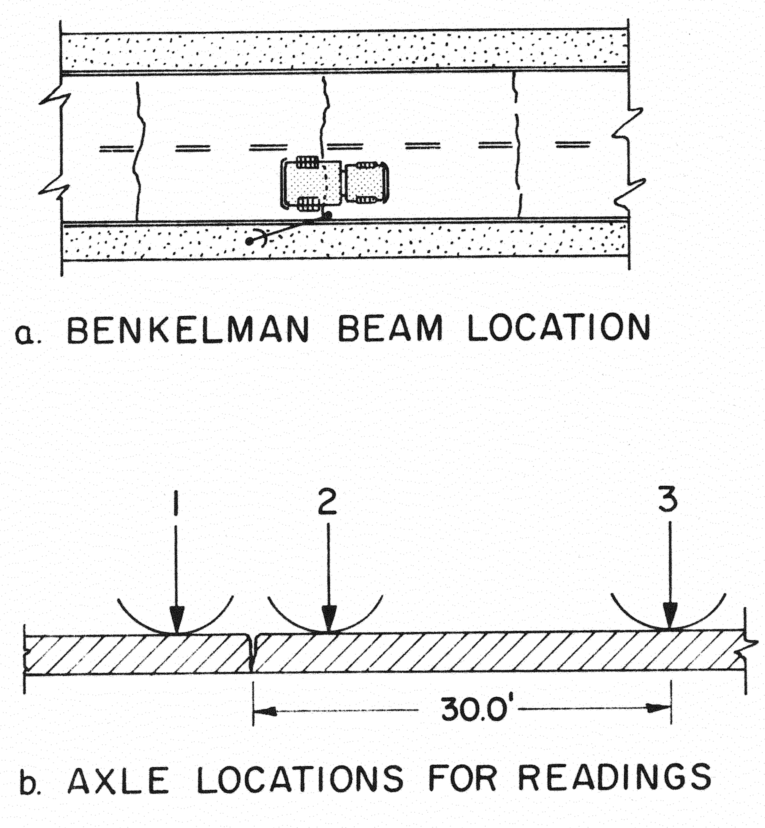


Figure 2. Measuring Vertical Movement With Benkelman Beam (22)

concerning field measurements of the horizontal movement at Portland cement concrete joints (1, 11, 20, 21). These studies showed the prominence of temperature effects. By plotting the amount of joint opening per degree change in temperature against the slab length, a straight line relationship was obtained and this relationship was used for practical estimation of the amount of joint opening to be expected. Unfortunately, this relationship does not apply to bituminous concrete pavements because of the difference in behavior of the respective materials. For example, the average thermal coefficient of expansion of asphalt concrete between 0° and 80°F is about four times higher than that of Portland cement concrete. Also, the variation in thicknesses and the lack of material uniformity in the respecitve layers of flexible pavements make it difficult to reliably predict crack widths for any given temperature change.

However, an approach that indicated the relative amount of horizontal movement at transverse cracks in flexible pavements was developed in a Minnesota study (8). This was accomplished through the use of an "effective crack spacing" concept which was defined as "the distance to the first transverse crack on both sides of the crack in question." Transverse cracks with different "effective crack spacing" were selected, steel nails were driven into the asphalt surfacing on each side of the crack 10 in. apart, and the amount of opening and closing of the crack was determined on subsequent dates as the temperature fluctuated. The results indicated that the relative horizontal movements at cracks in Minnesota flexible pavements was approximately equal to 0.01 in. per 10 ft of effective crack spacing.

Crack Surveying

The condition survey has long been recognized as a useful tool for rating or evaluating pavement performance. Reasons for rating a pavement are many and varied and as a result a large number of different methods have been developed (23, 24, 25, 26, 27). A good example of an objective method of rating is that developed by the Transportation Research Board in connection with the AASHTO Road Test (21).

At the present time, the most prevalent method of crack surveying, i.e., ascertaining if cracking has occurred and determining the number, type and condition of the cracks, is a visual one made by maintenance personnel either walking or driving slowly over a given section of flexible pavement. This method appears to be costly, time consuming, and extremely subjective, since the results of the survey depend largely on the experience and judgement of the observer. More objective rapid, and possibly economical methods using photography and data from profilometer studies have been used. In addition to the aforementioned advantages of these procedures, they also provide a record of the cracks and crack conditions for future reference and comparisons.

Aerial Photography

Color aerial photography has been used for pavement evaluation studies on a four-lane highway near Bangor, Maine (28). The factors that influence the amount of information on pavement distress features that can be obtained from photographic coverage were discussed. For studies of unsealed cracks, photo scales of 1.0 in. = 200 ft or larger were recommended. Sucessful application of this method requires personnel experienced in the field of both pavement evaluation and air-photo interpretation as well as the availability of the necessary photographic and viewing equipment.

Standard Photography

Some information has been received on standard photographic surveying procedures that are being developed by the Center for Highway Research at the University of Texas at Austin. This work is related to condition surveys of rigid pavements but should be applicable to crack surveying on flexible pavements. A camera equipped with an electric motor drive is used with different types of lenses to take photographs at the rate of 4½ frames per second. The camera is mounted on a boom in front of a vehicle approximately 8.0 ft above the pavement. Pictures of up to 77 square feet of pavement at a time were found possible at speeds up to 33 mph.

The ODOT's photologging equipment may also be applicable to crack surveying. The photographs made with this equipment are individual frames of 35 mm color film which are taken from a moving vehicle at equal distance increments of 0.01 mile. A data record image on each frame defines the mileage, route and date of filming. Preliminary investigation of such photographs showed that large cracks were readily visible and that counts of these cracks could be made easily on a given section of road. However, identification and counting of narrow cracks and determining the crack condition or contiguous deterioration at the cracks may be difficult due to the oblique nature of the photographs.

It may be possible to increase the angle of depression of the photo-logging camera and obtain photos more suitable for this aspect of crack surveying.

Profilometer Data

In an ongoing research study titled "Environmental Deterioration of Pavement" (29), the Texas Transportation Institute is working on a new method of crack counting utilizing data from profilometer runs. They have developed what they refer to as "crack counting digital filters" to analyze the profilometer data, count the cracks, and determine their severity and spacing. They reported that computer plots of the statistical filter runs compare favorably with visual surveys and inspection of the pavements.

CHAPTER III

QUESTIONNAIRE RESULTS

In order to obtain additional information on flexible pavement crack sealing practices, a mail survey was conducted. This survey consisted of a questionnaire (see Appendix I) which requested information on currently used sealants and methods of application, as well as the experience and opinions of field personnel relative to the magnitude of cracking as a maintenance problem and the general effectiveness of sealing cracks. These questionnaires were sent to the Maintenance Engineers of all eight Oklahoma Department of Transportation divisions and similar ones to the State Maintenance Engineers of Arkansas, Colorado, Kansas, Missouri, New Mexico, Tennessee and Texas.

Replies were received from all Oklahoma divisions and the selected states that were asked to complete the questionnaire. Abbreviated information contained in these replies has been tabulated and is presented in Tables II and III. The results of the survey are also discussed briefly under the following subject headings.

Sealing Materials

The sealing materials currently used in Oklahoma and surrounding states are predominantly standard types and grades of asphalt products, i.e., asphalt cements, cutbacks and both anionic and cationic emulsions. Some use is made of latex additives in emulsions and special products

TABLE II

SUMMARY OF QUESTIONNAIRE RESPONSES FROM OKLAHOMA DIVISION MAINTENANCE ENGINEERS

Division Number	What kind of sealant material is used in: A. Longitudinal B. Transverse C. Alligator		Are materials used now doing an effective job?	Is flexible pavement cracking a major maintenance problem?	Criteria used to determine necessity for sealing cracks?	Type of crack preparation prior to sealing operations.	Suggestions and Comments.	Method of periodic crack surveying.
	Material	Application Method						
1.	ABC. MC-3000 AB. CRS-2, wide cracks C. SS-1	pouring pouring spraying	Yes	No	Attempt to maintain a water-proof surface.	None, unless cracks are full of foreign materials.	None	Visual inspection, bi-weekly, quarterly and annually.
2.	AB. MC-250 SS-1 C. SS-1	pouring pouring spraying	No	Yes	Number of cracks per mile and crack must be open 1/16 in. or more.	Blowing, brooming, routing and priming when needed.	Sealant must be economical and easy to apply.	Visual inspection, day-to-day basis, during driving.
3.	AB. AC 60-70 Emulsions C. Emulsions	pouring pouring spraying	No	Yes, time consuming and costly.	Number of cracks per mile and crack must be open 1/16 in. or more.	Cleaning--blowing and brooming are required.	Need inexpensive sealant with more plasticity.	Visual inspection, periodic, to check for development and water infiltration.
4.	AB. AC 60-70 MC-800 SS-1 C. SS-1	pouring pouring pouring spraying	No	No	Crack must be open 3/16 in. for pouring. Extent of surface cracking for fog seals.	Blowing and/or brooming are required.	None	Visual inspection, daily observation for surface and base failures.
5.	ABC. MC-800 SS-1 SS-1 with Pliopave	injection pouring spraying	Yes, time needed for evaluation.	Yes	When cracks become apparent.	Blowing and brooming if needed.	Good results obtained with SS-1 blotted with limestone screenings which work their way into cracks and formed a slurry-type seal.	Visual inspection, regular basis, 3 to 4 times monthly.
6.	AB. MC-800 CRS-2 C. MC-800 CRS-2	pouring pouring spraying spraying	Yes	Yes, because most road bases are soil asphalt.	Number of cracks per mile and width of crack (not specified).	None	Sealing cracks is a never ending job, but is effective in this Division.	Visual inspection
7.	ABC. AC 60-70 AC 85-100 MC-800, 3000 CRS2h, SS-1	pouring pouring pouring pouring	Yes	No	Number of cracks per mile.	Blowing is required.	None	None
8.	A. AC 60-70 AC 85-100 AC 120-150 B. MC-800 SS-1	spraying spraying spraying spraying spraying	No	Yes	Number of cracks per mile (500) and crack must be open 1/32 in. or more.	None	Sealants with good resiliance are needed.	Visual inspection, every 60 days by driving.

TABLE III

SUMMARY OF QUESTIONNAIRE RESPONSES FROM SELECTED STATE MAINTENANCE ENGINEERS

State	What kind of sealant material is used in: A. Longitudinal B. Transverse C. Alligator — Material	Application Method	Are materials used now doing an effective job?	Is flexible pavement cracking a major maintenance problem?	Criteria used to determine necessity for sealing cracks.	Type of crack preparations prior to sealing operations.	Suggestions and Comments.	Method of periodic crack surveying.
Arkansas	ABC. RC-250, CRS-2 D-80, Lion Oil Co. (no distinction made as to type and grade of material used for sealing cracks.)	pouring pouring	Yes	Yes, sealing should be done on a regular basis.	Crack must be open 1/8 in. or more. Spalling and deterioration of surface adjacent to crack.	Brooming if crack is wide enough, and blowing are required.	Hopefully, a material of the nature of an unheated elastomeric polymer material can be found which will do a better job and last for 20 years.	Visual inspection, weekly by area foreman.
Colorado	ABC. MC-800 RC-800	pouring pouring	No	No	Deterioration of surface adjacent to crack.	Routing, blowing and brooming are required.	We question the benefits of crack sealing operations compared to the cost. In areas like Colorado with < 15" of rainfall, the moisture can't be causing much of a problem.	None
Kansas	ABC. CRS-1h (?)	pouring	Yes	No	Crack must be open 3/16 in. or more.	Blowing with air is required.	Prior to letting a resurfacing contract, a formal inspection of roadway is conducted and the number of cracks and crack pouring are factors considered in this inspection.	No formalized inspection for cracks. Crack surveillance is a routine function of field personnel.
Missouri	AB. RC-800 CRS-2 C.	pouring pouring seal or resurface	Yes	No	Crack must be open 1/8 in. or more. Spalling and deterioration of surface adjacent to crack.	None. Work is done in latter part of the year when temperature is below 40°F and cracks are open.	By far, the majority of crack sealing is done with RC-800. The RC is not used when pavement is wet and CRS-2 is not used below freezing.	None
New Mexico	ABC. MC-250 MC-3000 plus Gilsonite	pouring and pressure injection	Yes	Yes	Crack must be open 1/8 to 1/2 in. or more.	None. If crack is deep, it is partially filled with small rock (1/4 to 3/8 in.)	Have experimented with many commercial crack sealants, but found that an MC/Gilsonite mixture works best. Use 50-75% Gilsonite by weight.	Visual inspection, continuously by maintenance forces.
Tennessee	ABC. RC-250	pouring	Yes	No, scheduled resurfacing tends to keep this from becoming a major problem.	Crack must be open 3/16 in. or more.	Blowing and temperature range 30° to 70°F for applying sealant is required.	None	Visual inspection, daily.
Texas	ABC. RC-250, HVRS with and without latex, cat-blown asphalt, 75 and 42 penetration.	pouring and/or spraying	Yes	Yes	Crack must be open 1/8 in. or more. Deterioration and excessive alligator cracking.	Blowing, routing, brooming are sometimes used, but not required.	Sealants currently being used are effective but can be improved. Current methods are very expensive. Have also used hot-poured rubber, but due to cost and heating problems, it has been discontinued.	Visual inspection, periodically by foreman and annually by trained rating teams.

(exact type unknown) were reported used in Arkansas and Texas. New Mexico reported using Gilsonite as an additive in medium curing cutbacks with the percentage by volume of the Gilsonite varying from 25% in the summer to 50% in mixtures used during colder weather.

Apparently, there is no standard sealant for treating longitudinal and transverse cracks in Oklahoma. Four divisions use 60-70 and/or 85-100 penetration asphalt cements as well as medium curing cutbacks and emulsions for this purpose. The other divisions use medium curing cutbacks (250 to 3000 grades) or anionic and cationic emulsions for these types of cracks. The majority of the surrounding states favor the use of rapid curing cutbacks (250 and 800 grades) or cationic rapid setting emulsions for sealing all categories of cracks. Texas reported using asphalt cements that had been catalytically blown to penetrations of 42 and 75.

In Oklahoma, slow setting anionic emulsion (SS-1) is used predominatly for sealing alligator type cracking and in some divisions it is also employed on longitudinal and transverse cracks. Division 5 reported excellent results obtained by filling the wider cracks with SS-1 and then blotting the surface with limestone screenings to form a slurry-type seal. The surrounding states that use emulsions prefer the cationic type for sealing alligator cracks, and Divisions 1, 6, and 7 also employ CRS-2 and CRS-2h emulsions for this purpose.

Criteria Used to Determine Necessity for Sealing

The majority of the Oklahoma divisions use some number of cracks per mile of roadway <u>and</u> crack widths, varying from 1/32 in. to 3/16 in. or more, as a basis for deciding the need for sealing operations.

Other divisions simply try to maintain a waterproof surface on the roads or begin sealing when the cracks become apparent. Most adjacent states utilize crack width (1/8 in. or more) and/or deterioration of the surface adjacent to the crack as the determining criteria for applying sealants.

Crack Preparation

The replies from the respondents to the question concerning the types of crack preparation made prior to sealing operations can be grouped into three catagories:

1. Crack preparations are required. These preparations include brooming, blowing, routing, priming and partial filling of large deep cracks with fine aggregate, in various combinations.

2. No crack preparation required. Various combination of the above treatments are used when needed. The decision is apparently left to the experience and judgement of the maintenance personnel. Time and availability of equipment probably influence the ultimate decision.

3. No crack preparation at all prior to sealing operations.

Application Methods

Application methods used by the respondents seemed to be rather uniform. That is, hand pouring of the sealant is used on the more open or wider types of cracks and spraying on the more narrow and closely spaced cracks. Distributor truck spraying with hand wands or from the spray bar depends on the extent of the crack system. Pressure injection of sealants into the cracks was listed by one division and one of the selected states.

Specialized Mechanical Equipment Used

The questionnaire requested information on special mechanical equipment used for crack preparation and sealing work. None of the respondents indicated any experience with or use of apparatus beyond that which would be considered normal equipment for maintenance crews engaged in sealing cracks.

Pavement Inspection and Crack Surveying

All replies indicated that visual inspection was the only method used to survey flexible pavements in order to determine crack development and extent of surface deterioration at the cracks. This type of inspection is probably carried out largely from slow moving vehicles and in some cases by walking observors. Seven of the Oklahoma divisions and five of the states reported that they made periodic crack surveys with this technique. Generally, these surveys or inspections on a given section of road are carried out by the maintenance personnel responsible for that section. Texas indicated that specially trained rating teams performed such surveys annually in some of their districts.

Is Cracking a Major Maintenance Problem?

In the opinion of the Oklahoma respondents, 62% considered flexible pavement cracking a major maintenance problem, while 38% did not. In contrast, only 43% of the respondents from the surrounding states thought it a major problem and 57% did not. It is difficult to interpret these replies and the answers, apparently, are related to a number of factors such as:

1. geographic location, i.e., temperature ranges and annual rainfall amounts;

2. type of base materials employed;

3. type of subgrade soils;

4. traffic volumes and weights;

5. efficiency of sealants being used;

6. philosophy of the agency as related to the cost-benefit ratio of sealing operations, i.e., it may be more economical in some cases to ignore cracking and schedule complete resurfacing as surface conditions deteriorate beyond a tolerable level.

Are Sealants Effective?

Replies from 50% of the Oklahoma divisions states that the presently used sealant materials were not doing an effective job of sealing the cracks, while 86% of the surrounding states considered their sealants to be effective. Again, these replies are considered to depend on some of the above mentioned factors, as well as the type of crack preparations and sealants employed and the timing of the sealing operations. Intuitively, sealing cracks as soon as possible after they occur will help to preserve the integrity of the total pavement system and extend considerably the useful life of the surface.

Suggestions and Comments

The comments and suggestions received on all of the questionnaires are briefly summarized as follows:

1. A sealant should be economical and easy to apply.

2. Crack sealing is time consuming--need some type of inexpensive sealant that has more plasticity.

3. Good results achieved this season with SS-1 emulsion blotted with good limestone screenings. Screenings work their way into cracks and appear to form a slurry-type seal. Time needed for further evaluation.

4. Crack sealing is a never ending job, but is effective.

5. In second year after application the sealants have no resilience and the crack re-opens.

6. A material of the nature of an unheated elastomeric polymer is needed that will last 15-20 years.

7. We question the benefits compared to cost of crack filling operations in areas with less than 15 in. of annual precipitation.

8. The majority of our crack sealing is done with RC-800 when temperature is below 40°F and joints are open.

9. Scheduled resurfacing tends to keep cracking from becoming a major problem.

10. Sealants currently being used are effective but could be improved. Current methods of application are expensive. We have also used hot-poured rubber (asphalt cement with rubber additive) but discontinued this due to cost and problems with heating equipment.

11. We have experimented with a great many commercial crack sealants but have found that an MC/Gilsonite mixture works best.

CHAPTER IV

SUMMARY AND SUGGESTED RESEARCH APPROACH

Based on the results of the in-state survey, there is a wide variation in the types and grades of sealants employed, crack preparation procedures used, and results achieved. The opinions of field personnel are divided as to whether flexible pavement cracking is a major maintenance problem in their respective divisions and as to the effectiveness of the sealants that are generally used.

This division of opinion is not too surprising considering the variation in conditions in the divisions, e.g., annual rainfall amounts, average temperature ranges, base materials used, subgrade soil types, and different traffic characteristics. Some sealants may work well in one location but not in another due to one or more of the above factors. However, through an investigation of the most effective sealant materials and application techniques reported in the survey and in the literature, it should be possible to establish more uniformity in crack sealing procedures and sealants used throughout the state and thereby more uniform and effective results from these operations.

Such an investigation should be divided into several parts or phases. The first, or laboratory phase, will be directed towards evaluating and/or developing laboratory test procedures for sealant materials that will reasonably predict their field performance. After establishing the desirable characteristics and properties of an effective long lasting crack sealing material, these laboratory tests can be used to ascertain whether a prospective sealant conforms to the selected criteria.

A second phase, actually peripheral to the laboratory part of the investigation, will be a field study of crack movements and behavior under varying loading and temperature conditions. This study will be necessary to help establish reasonable criteria for sealants based on average conditions in Oklahoma.

The last phase will consist of a field test program to evaluate the effectiveness of various application procedures and materials for sealing cracks. The results of field testson selected sealants will assist in determining the validity of the proposed series of laboratory tests. In addition, the final phase of the investigation should include efforts directed to developing a technique for rapid surveying and recording of crack conditions on flexible pavements.

This type of investigation will, of necessity, span a considerable period of time (3 to 4 years) and the results of the initial phases of the research will control, to a considerable extent, the planning and conduct of the final phases. As requested, an outline of the initial phases of the investigation, i.e., the envisioned laboratory and field work devoted to evaluating sealants and studying crack dynamics,is presented.

Laboratory Tests

The proposed series of laboratory tests are primarily standard types designed to evaluate both performance characteristics and certain physical properties of crack sealing materials. Performance characteristics include adhesion and ductility under extension at low-temperature and sealant compatibility with the asphalt binder in the pavement. Physical and/or rheological properties include consistency, flow, resilience and shrinkage.

Based on the more effective or more widely used sealants reported in the in-state survey, six sealants are suggested for initial evaluation by the proposed laboratory tests. These sealants are as follows:

Asphalt Cements: AC 60-70 and AC 85-100

Cutbacks: MC-800 and MC-3000

Emulsions: SS-1 (with Pliopave) and CRS-2

Bond Ductility Test

This test is an attempt to duplicate field crack conditions with regard to the tensile stresses imposed on the sealants. It is a basic test used by many previous investigators of sealant characteristics and the results of this test are considered of primary importance in many specifications. The essential features of the test and the necessary equipment have been described in Chapter II.

The extension machines used by the respective agencies or investigators cited are either not commercially available, not reasonably priced, or not considered suitable for this investigation. Therefore, it is proposed to construct such a device capable of testing six specimens simultaneously and which will fit into a presently available low-temperature cabinet. A general concept of the construction of this apparatus is presented in Fig. 3 and Fig. 4. The estimated cost of the materials and labor to fabricate this equipment is approximately $1750.00

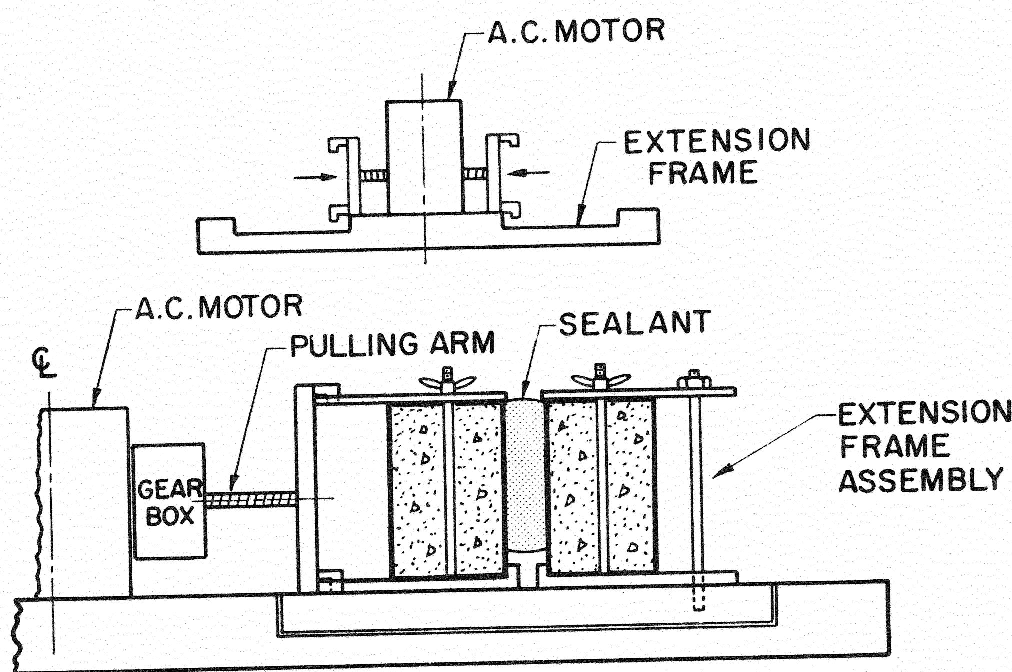
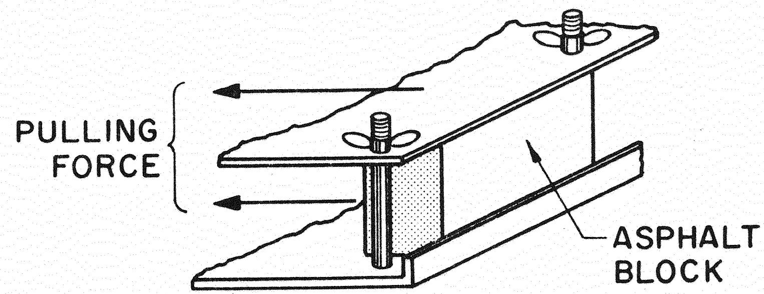
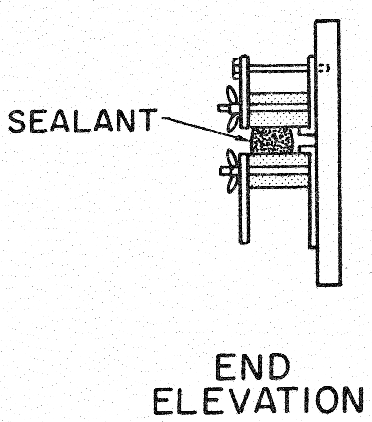


Figure 3. General Lay-Out of The Proposed Extension Machine





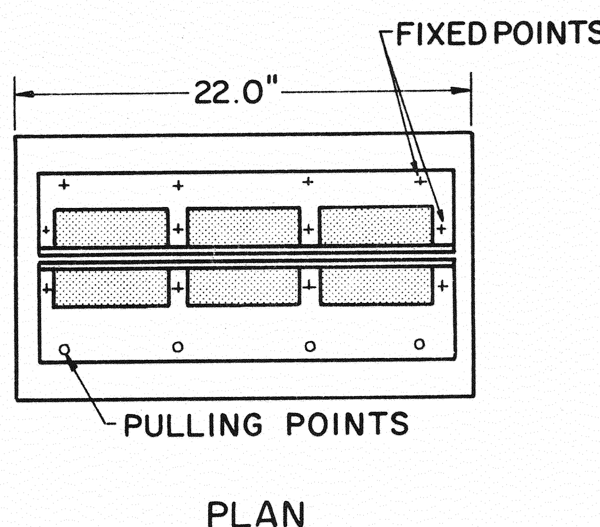


Figure 4. Extension Assembly for Three Test Specimens

Extension of the test specimens clamped in the extension frames will be accomplished by two screws driven by an electric motor through gear reductions. The rate of extension will be a uniform 1/8 in./hr and the test will be conducted at a temperature of 0°F. The expected number of cycles of extension and compression until failure occurs will range from three to five under these severe conditions.

The test variables will be the dimensions of the sealer between the test blocks and, of course, the number of cycles required to produce some type of failure. Three widths and depths of sealant are proposed: 1/8 in. width and 2 in. width, 1/4 in. width and 2 in. depth and 1/4 in. width and 1 in. depth. The sealants will be poured between the test blocks held in jigs that conform to these dimensions.

The dimensions of the test blocks are shown in Fig. 5. The basic block will be made from an asphalt concrete surface course mixture compacted in a specially designed steel mold mounted on a carriage system. Compaction will be achieved using a kneeding compactor with a rectangular foot as indicated in Fig. 6. After compaction to a relatively high density and extraction from the mold, the blocks will be sawed in half. This will provide the specimen blocks between which the sealants will be poured.

Penetration Test

This test provides a measure of sealant consistency and is similar to the standard penetration test except that a cone is used instead of the penetration needle. The test procedure is outlined in ASTM D 3407-75T (13). This is a tentative test designed for hot-poured sealants but it should be applicable to cold-poured materials after they have

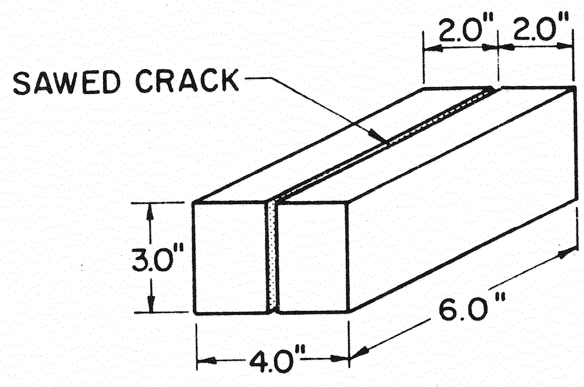


Figure 5. Bond-Ductility Test Block

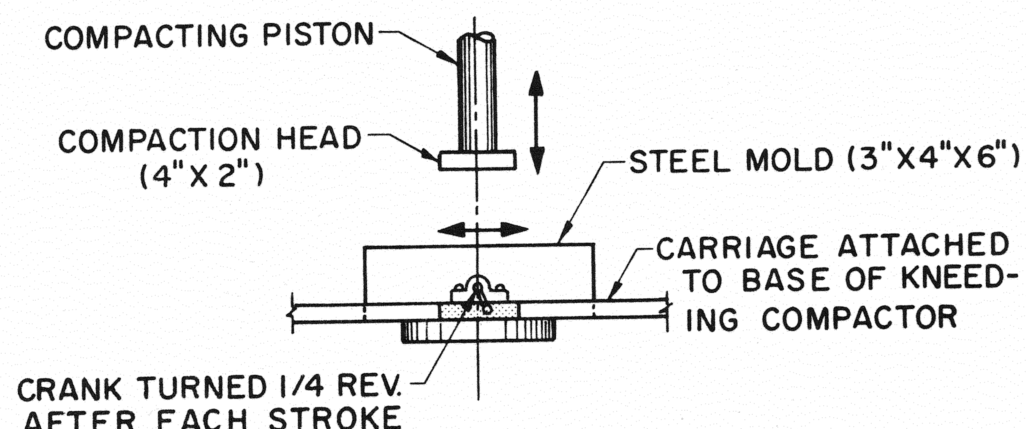


Figure 6. Mold Carriage System for Compacting Test-Blocks

cured (cutbacks) or set (emulsions) and approach the consistency of the base asphalt cement used in their preparation.

It is proposed to develop procedures for accelerating the curing or setting processes of the liquid type sealants by drying them in an oven for specified periods of time. These procedures will permit direct comparison of the characteristics and properties of both hot and cold-poured sealants.

Flow Test

This tentative test procedure for hot and cold-poured mastic type materials is outlined in ASTM D 3407-75T (13). It is designed to show the amount of flow of the sealant at an elevated temperature (140°F). Again, drying or curing procedures will have to be employed in order to evaluate this property of liquid asphalt sealants.

Resilience Test

The procedure for performing this test is described in ASTM D 3407-75T (13) and the test values provide an indication of the elasticity of the sealant material. A standard penetrometer apparatus is used but a ball shaped penetration point is substituted for the needle. The ball point is allowed to penetrate the sample for five seconds, the reading is recorded, and then the point is pressed into the sample an additional 1.0 cm in depth. The penetrometer clutch is then released and the ball and weighted shaft permitted to rise for twenty seconds before the final reading is made. The results are reported as the recovery percentage or percent of recovered depth of penetration.

Compatibility Test

Asphalt products from different sources may not be compatible with each other. That is, their different chemical compositions are such that they cannot be placed together without the occurrence of harmful reactions. Thus, crack sealants can react with the asphalt binder in the pavement and reduce the effectiveness of the seal. This test procedure and attendant failure criteria are presented in ASTM D 3407-75T (13). The test consists of pouring the sealants in a groove cut into the top surface of asphalt concrete test specimens. The specimens and applied sealants are placed in a 140°F oven for 72 hours, allowed to cool and then examined for any deleterious effects.

Volume Change Test

The purpose of this test is to determine the amount of shrinkage or volume change than can be expected from cold-poured sealants. Calibrated containers are filled flush with their tops with the sealant and then cured in an oven for a specified period of time. After curing, the containers are cooled to 5°F and then filled with water. The volume of added water is considered as the amount of shrinkage of the sealant.

Field Study of Crack Movements

The proposed field study of horizontal and vertical crack movements will be limited to transverse type cracks, since the relative movements of the adjacent pavement sections should be greater than for the other types of cracks. It would be desirable to select five pavement locations with transverse cracking in the eastern, western, northern, southern and central parts of Oklahoma for this study. It would also be desirable to have these locations on pavement sections with different types of base and subgrade soil.

These locations will consist of one or more transverse cracks that will be marked and monitored at regular intervals during a twelve month period. Each of the selected locations will be identified for the respective division maintenance personnel so that sealing or overlaying operations will not be carried out at these sites during the study period.

Measurement of Horizontal Movements

The horizontal movements at the selected transverse cracks will be determined using the approach developed in Minnesota (8). Steel concrete nails will be driven into the pavement on each side of the crack approximately 10.0 in. apart, as shown in Fig. 7. The nails will be driven flush with the surface of the pavement and an indentation made in the top of each nail with a punch. These indentations will serve as fixed reference points for the subsequent measurements of the amount of opening and closing of the crack.

At monthly intervals, the spacing of these nails will be measured to the nearest 0.01 in. using a caliper rule equipped with gage points to fit the indentations in the nail heads. The air temperature, the pavement surface temperature, and the pavement temperature at a depth of 2.0 in. will be determined at the time of the horizontal spacing measurement. Remote sensing tele-thermometer equipment (presently available) employing thermistors will be used for these temperature measurements.

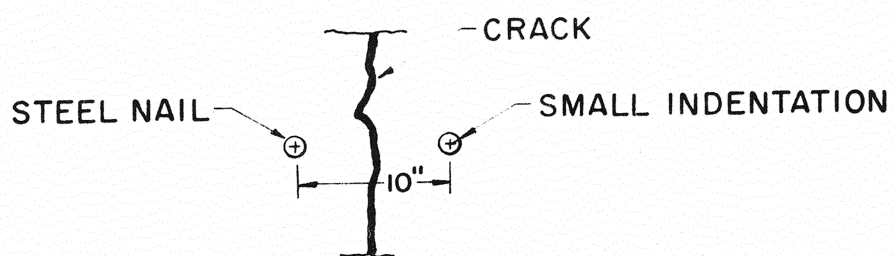


Figure 7. Position of Reference Nails

The data, thus obtained, will be analyzed statistically and the results should indicate the amount of horizontal movement at these cracks that can be expected at various times during the year and the influence of ambient temperatures on this movement. Hopefully, the selection of the crack locations can be made so as to obtain different "effective crack spacing". If this can be done, the average relative horizontal movement of these cracks in Oklahoma can be expressed in terms of in./ft of effective crack spacing and a comparison made with the results of the Minnesota study.

Measurement of Vertical Movements

It is proposed to use the method of measuring vertical movements at flexible pavement cracks that was employed in the previously cited Virginia study (22). That is, the relative vertical deflections of each side of a transverse crack will be determined by using a Benkelman beam and a truck with an 18,000 lb rear axle load. The procedure for this method of measurement was described in Chapter II. The beam readings will give the deflection at the crack caused by the axle load and also the differential deflection of the two sides of the crack.

It is suggested that the Research Division of ODOT provide a crew experienced in the use of the Benkelman beam and the loaded truck for these measurements. Because of the difficulty in scheduling cooperative field work of this nature, a different monitoring schedule from that proposed for the horizontal displacement measurements should be used. It is believed that the necessary data and information on vertical deflections at the selected crack locations can be obtained from four measurements. These measurements visits, will be scheduled at the respective locations during the summer, fall, winter and spring periods of the year.

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APPENDIX I

QUESTIONNAIRE FORM

QUESTIONNAIRE

Flexible Pavement Crack Sealing Study

1. What type of sealant materials have been used successfully in your Division of sealing the following types of cracks in flexible pavements?

Longitudinal Cracks: (Please check one or more and supply additional information)

_____ Asphalt cements; penetration grade used _____________________.

_____ Rubberized A.C.'s penetration grade and % rubber _____________.

_____ Cutback asphalts; type and grade _________________________.

_____ Asphalt emulsions; type and grade ________________________.

_____ Other sealants; please specify __________________________.

Transverse Cracks: (Please check one or more and supply additional information)

_____ Asphalt cements; penetration grade used _____________________.

_____ Rubberized A.C.'s penetration grade and % rubber _____________.

_____ Cutback asphalts; type and grade _________________________.

_____ Asphalt emulsions; type and grade ________________________.

_____ Other sealants; please specify __________________________.

Alligator or Map Cracks: (Please check one or more and supply additional information)

_____ Asphalt cements; penetration grade used _____________________.

_____ Rubberized A.C.'s penetration grade and % rubber _____________.

_____ Cutback asphalts; type and grade _________________________.

_____ Asphalt emulsions; type and grade ________________________.

_____ Other sealants; please specify __________________________.

2. In your Division, what criteria are used to determine the necessity for sealing flexible pavement cracks?

_____ Number of cracks per mile of roadway.

_____ Width of Crack; please specify width ______________________.

_____ Spalling or deterioration of surface adjacent to crack.

_____ Other; please specify ____________________________________

____.

3. Does your Division require any type of crack preparation, i.e., blowing, brooming, routing, priming, etc., prior to application of the sealant? _____.
If so, please specify treatment _________________________________

____.

4. In your Division, what is the predominant method of applying sealants to the respective types of cracks (e.g., pouring, spraying, pressure injection, etc.)?

____.

Longitudinal cracks ______________________________.

Transverse cracks ______________________________.

Alligator or map cracks ______________________________.

5. Does your Division utilize any specialized mechanical equipment for crack preparation and sealing ? ____________. If so, please list the names of this equipment and their purposes. ______________________________

____

____

____

6. Does your Division conduct periodic inspections or surveys of its flexible pavements to ascertain crack development and/or extent of surface deterioration at the cracks? ____________. If so, please describe briefly the method of survey used and the frequency of the surveys.______________________________

____

____

____

7. In your opinion, is flexible pavement cracking a major maintenance problem in your Division? ______________________________

____

____

8. In your opinion, are the presently used sealants doing an effective job ? _____

9. Additional comments and suggestions : ______________________________

____

____

____

10. Name ______________________. Division No. ______________________.

THANK YOU for your time and efforts in completing this questionnaire !!!!